An All-polymer Thin-film Scanning Optical Filter for 3D-image Displays

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ABSTRACT

We've built a transparent thin-film scanning optical filter, which can be attached to displays to show 3D-images. The scanning motion provides more quality images depending on the viewpoints. Water droplets are put in the filter as microlenses which is driven electrostatically. All the structure of the filter, including conductive elements, is made of transparent polymer films. The electrodes to drive the microlenses are conductive polymer Baytron P® patterned with a new technique using selectivity of hydrophobic and hydrophilic regions on the surface. Since the scanning filter consists of multi layers, new functions can be easily added by attaching another layer on top or bottom of the filter. In this paper, an LCD (liquid crystal display) was attached to the bottom as a light source layer.

INTRODUCTION

IP (Integral Photography), invented in 1908[6, 7], is a 3D-imaging method with a microlens array on printing paper. Although IP is an excellent way to display 3D images without any glasses or HMDs, it has not been applied to electrical appliances because of its poor imaging resolution so far. On the other hand, we proposed a compound-eye-shaped micro visual sensor, where the motion of the photoreceptors enhances the spatial resolution of the optical sensor [3]. This "retinal scanning" can be applied to IP-based displays to increase the imaging resolution.

Since polymers are cheap and easy to reshape, they are promising materials for future MEMS products. Several fabrication techniques for polymers[2,4,12] have been introduced. Our polymer thin-film scanner is fabricated suitably through batch processes, such as molding, shadow-masking and spin-coating.

In designing the scanning layer, a transparent material is desirable because it can transmit light with smaller loss of energy. In addition, transparent scanning elements can be arranged just over the light sources, so that the whole optical system becomes very thin compared with the one using reflecting mirrors. Liquid is used as micro optical elements [5,9,11] to transmit light effectively. We can take advantage of several studies which have been recently reported on liquid handling techniques[1,10].

PRINCIPLE AND FABRICATION

Figure 1 illustrates the principle of the 3D-imaging method, where a scanning microlens array is combined with an IP-based visual system. By showing slightly rotated images synchronized with the scanner control, 3D-image information is projected in front of the display. According to the principle of Retinal Scanning, the angular resolution $\Delta\varphi$ of a 3D image is determined by the angular scanning amplitude $\Delta\alpha$, scanning frequency f_{scan} and the imaging frequency f_{image} of the base visual system in the following way;

$$\Delta\varphi = (\Delta\alpha \cdot f_{scan,}) / f_{image}. \quad (1)$$

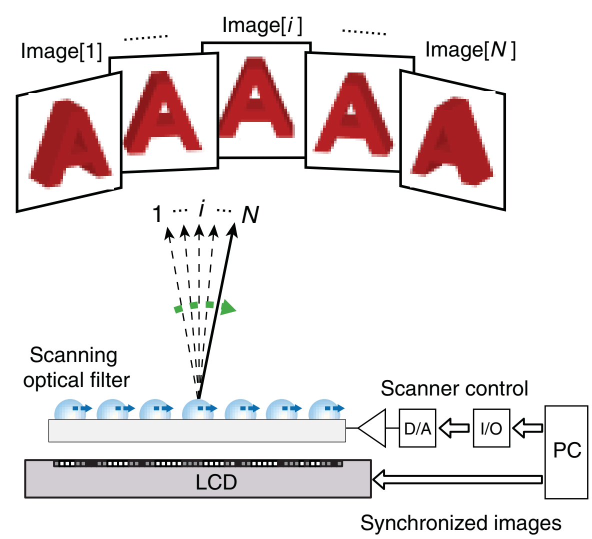

Figure 1. Principle of the 3D-imaging method. By showing different images 1 to N synchronized with the scanner control, 3D information can be displayed.

Figure 2 shows the fabricated filter structure. In this case, the size of a scanning element is 2460 µm x 2460 µm, which is designed to fit 12 x 12 pixels of the LCD light source layer. The filter is composed of three main functional layers. A magnifier-lens layer was made of cured PU (polyurethane) transferred from melted patterned photoresist [8]. This top layer is used to adjust scanning amplitude. The top lenses could be designed to either amplify or attenuate the image.

Packaging layer is made of PDMS

(polydimethylsiloxane). The negative master obtained by patterning SU-8 on a silicon substrate. The master is transferred to PDMS to form chambers preventing the droplet lenses from drying.

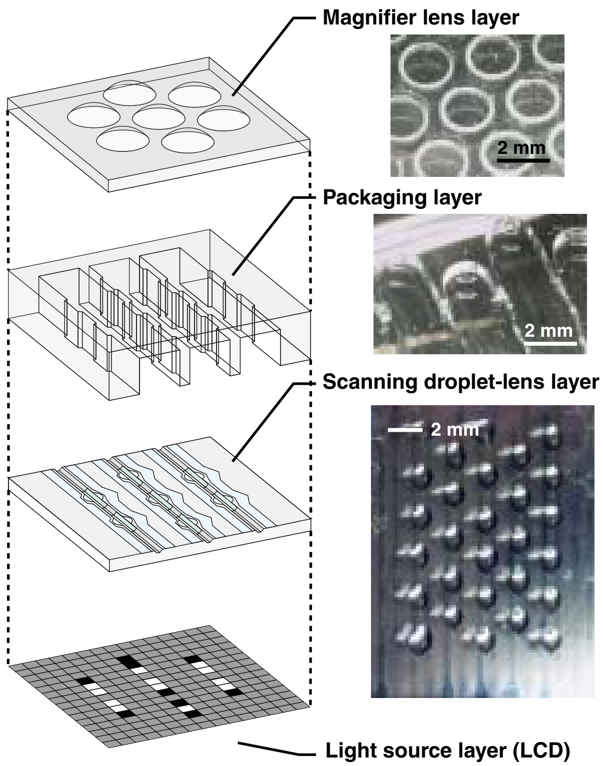

Figure 2. The scanning filter consists of three main transparent films. It is easy to add functions by attaching another functional layer on top/bottom of the filter. An LCD was used as a light source layer.

Figure 3 shows photographs of the scanning droplet-lens layer. Droplets, introduced onto the layer using a pico-litter pump, normally stay stable on the hydrophilic areas. The diameter, height and contact angle of a lens are typically 200μm, 120μm and 100degrees, respectively. When voltage is applied to the electrode, the droplet moves towards the driving electrode. In order to obtain repeatable scanning motion, the attraction of the hydrophilic part should be large enough to move the droplet back to its home position. Grooves are fabricated on the substrate to promote the attraction.

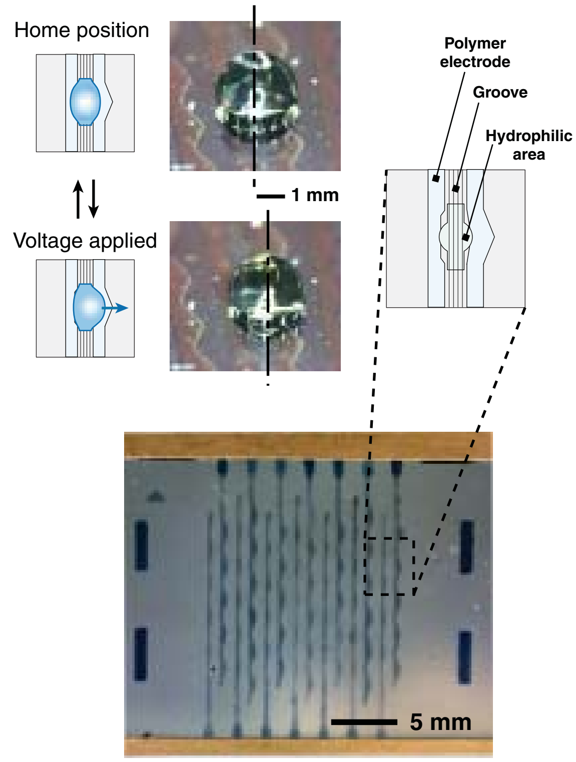

Figure 3. Photographs of the scanning layer. Droplets are normally attracted to the hydrophilic areas. Grooves were made to ensure the attraction.

Figure 4 is the process flow of the scanning lens layer. A 500 μm-thick PET (polyethylene terephthalate) film was used as a substrate. In order to avoid the deformation of the PET substrate, all the following steps must be done under 70ºC. Using a mold made of PDMS, grooves, which was originally made on a silicon wafer by TMAH wet etching, was transferred into a cured PU layer on the PET substrate[12].

Patterned conductive polymer, Baytron P®, was used as the driving electrodes. We propose a new polymer-curing method to pattern Baytron P. Firstly, Cytop® was spincoated and plasma-etched to introduce the hydrophobic/hydrophilic areas. When Baytron P® was dispensed and spun on the Cytop-patterned surface, it is repulsed from the hydrophobic areas and cured only on the hydrophilic areas. The width of the electrode is 300μm at the narrowest points. Using this technique, Baytron P can be patterned without any masking materials such as photoresist or metal, which might affect the conductivity of the layers.

After insulating the conductive layer by a 1μm-thick Parylene C, Cytop was coated and patterned again to make hydrophilic spots defining the home position of the droplet.

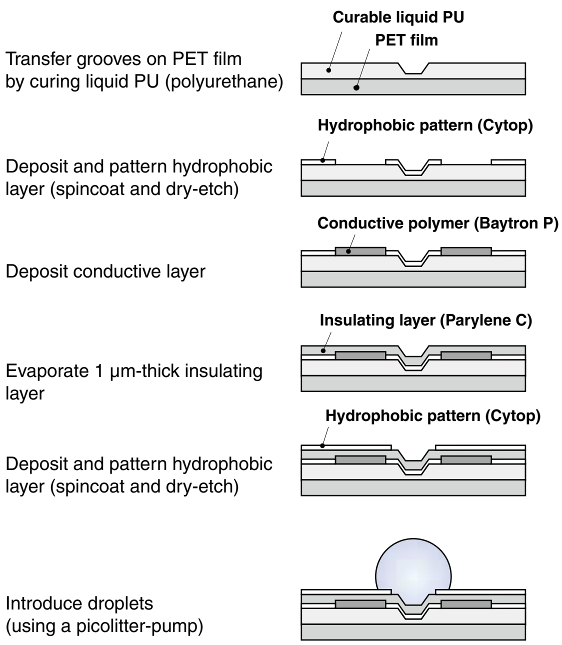

Figure 4. Fabrication process of the scanning layer. All the structure is made of polymers. Conductive polymer Baytron P was deposited on the patterned hydrophilic areas to forms electrodes.

Conductivity of Baytron P was measured for several patterning conditions. The line resistance (= resistance per length) of Baytron P with different width was measured for different spin speed (Figure 5). Lower conductivities were measured for patterns cured at higher spin speeds. When the width of hydrophilic lines is narrower, the surface tension force of liquid Baytron P becomes dominant and the line resistance becomes less dependent on the spin speed. Spin speed has a dominant effect on the conductivity for wider patterns. The sheet resistance (= resistance per square) was calculated as a ratio of the line conductivity to the width as shown in Figure 6.

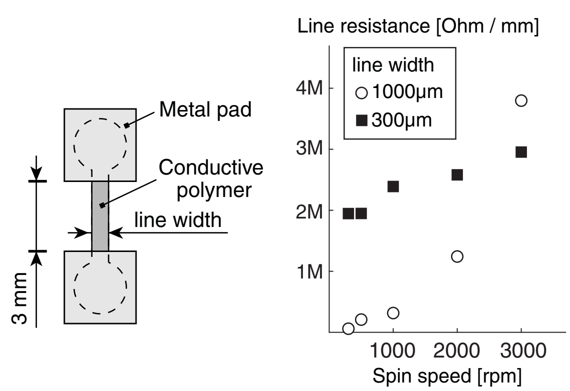

Figure 5. Conductivity of patterned Baytron P was measured for two different spinspeed.

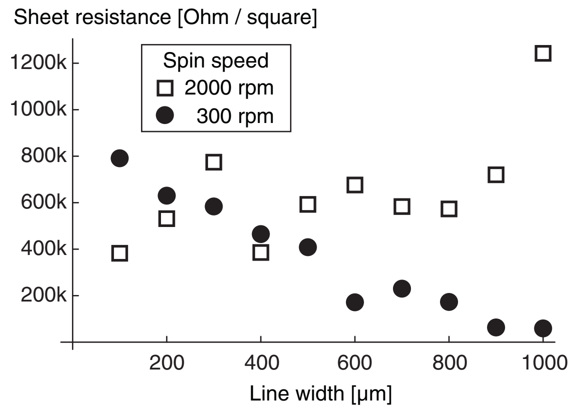

Figure 6. Sheet resistances of the conductive polymer changes with different line width.

EXPERIMENTAL RESULTS

The displacement of a droplet at several applied voltages was measured by plotting the center of the droplet on side-view photographs (Figure 7 top right).

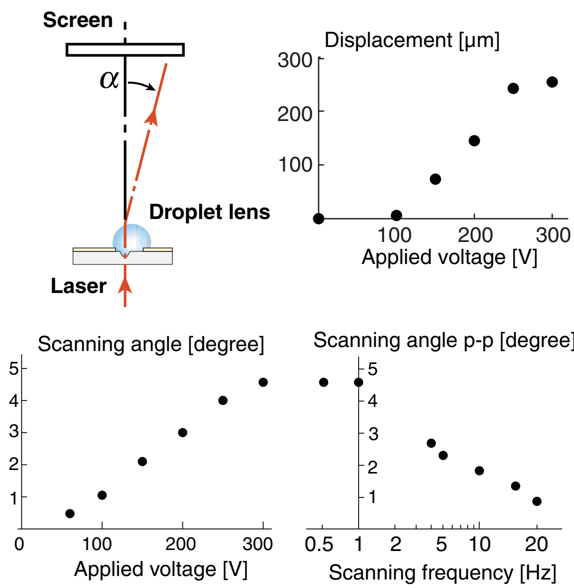

Figure 7. Characteristics of a droplet lens scanner. Scanning amplitude of 2.5degrees at 300Vp-p, 4Hz was observed.

In order to measure the optical characteristics of the filter, a spot laser was cast on a scanning lens from the bottom side (figure 7 top left). The amplitude of 2.5 degrees was observed when applying 300Vp-p at 4Hz. When the imaging frequency of the LCD, f_{image}, is assumed to be 30 frames/sec, the imaging system will display images toward seven different directions respectively. According to equation (1), the angular resolution $\Delta\varphi$ is 0.33 degrees.

The scanner was placed on an LCD display.

When voltage is applied to the electrode, the light intensity from the green pixel decreases. The intensity from the red pixel increases, contrary. The data in Figure 8 was taken by a CCD digital camera used at a fixed shutter speed and an aperture. During this operation, the LCD projected the same image to keep the light intensity constant. The change of the intensity in Figure 8 was only caused by the lens motion. The result shows the scanning amplitude is large enough to sweep the gap between the LCD's adjacent pixels.

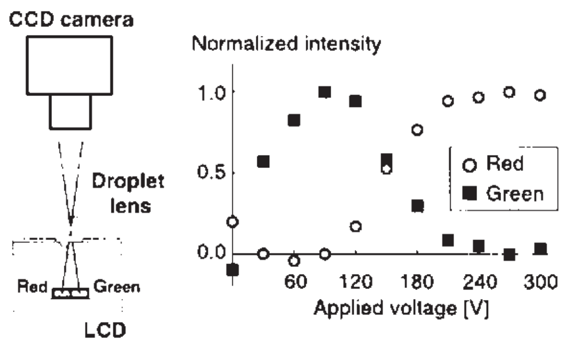

Figure 8. When voltage is applied, the green pixel gets out of the view (It can be seen from other view points.) and the red pixel comes into the view.

CONCLUSION

We've built a transparent optical scanning filter for a 3D-image display to increase the spatial resolution by Retinal Scanning. The filter has an array of scanning elements including droplet microlenses driven by electrostatic force. Although the filter is originally designed to realize a high-resolution 3D-imaging system, the newly proposed transparent multi-layer structure is applicable to several kinds of μ-TASs requring optical operations.

From the result, we can conclude that the scanner yields enough scanning amplitude to cover the inter-visual angle between two adjacent light sources, and that retinal scanning can enhance the spatial resolution for a 3D-image display.

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